

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
12 July 2001 (12.07.2001)

PCT

(10) International Publication Number  
**WO 01/50483 A1**

(51) International Patent Classification<sup>7</sup>: **H01F 3/04**, 41/02

(21) International Application Number: PCT/US01/00099

(22) International Filing Date: 3 January 2001 (03.01.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
09/477,905 5 January 2000 (05.01.2000) US

(71) Applicant: **HONEYWELL INTERNATIONAL INC.**  
[US/US]; 101 Columbia Avenue, P.O. Box 2245, Morristown, NJ 07960 (US).

(72) Inventors: **DECRISTOFARO, Nicholas, John**; 33 Lincoln Avenue, Chatham, NJ 07928 (US). **FISH, Gordon,**

**Edward**; 103 Lorraine Avenue, Upper Montclair, NJ 07043 (US). **STAMATIS, Peter, Joseph**; 107 Washington Avenue, Morristown, NJ 07960 (US).

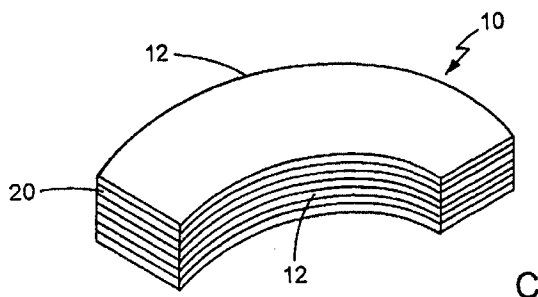
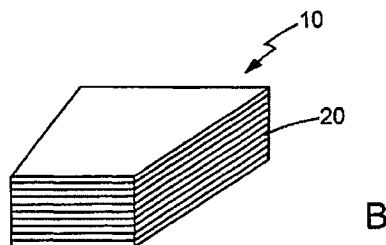
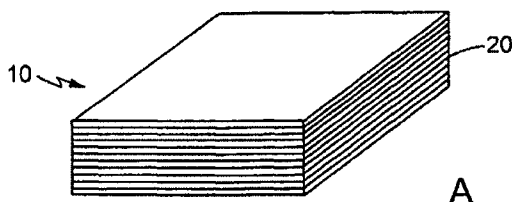
(74) Agent: **CRISS, Roger, H.**; Honeywell International Inc., 101 Columbia Avenue, P.O. Box 2245, Morristown, NJ 07960 (US).

(81) Designated States (*national*): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,

[Continued on next page]

(54) Title: **BULK AMORPHOUS METAL MAGNETIC COMPONENT**



(57) Abstract: A bulk amorphous metal magnetic component has a plurality of layers of amorphous metal strips laminated together to form a generally three-dimensional part having the shape of a polyhedron. The bulk amorphous metal magnetic component may include an arcuate surface, and preferably includes two arcuate surfaces that are disposed opposite each other. The magnetic component is operable at frequencies ranging from between approximately 50 Hz and 20,000 Hz. When the component is excited at an excitation frequency "f" to a peak induction level  $B_{max}$ , it exhibits a core loss less than "L" wherein L is given by the formula  $L = 0.0074 f(B_{max})^{1.3} + 0.000282 f^{1.5}(B_{max})^{2.4}$ , said core loss, said excitation frequency and said peak induction level being measure in watts per kilogram, hertz, and teslas, respectively. Performance characteristics of the bulk amorphous metal magnetic component of the present invention are significantly better when compared to silicon-steel components operated over the same frequency range.

WO 01/50483 A1



IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

— *With international search report.*

## **BULK AMORPHOUS METAL MAGNETIC COMPONENT**

### **CROSS-REFERENCE TO RELATED APPLICATION**

5           This application is a Continuation-in-Part of Application Serial Number 09/186,914, filed November 6, 1998, entitled "Bulk Amorphous Metal Magnetic Components."

### **BACKGROUND OF THE INVENTION**

#### **1.     Field Of The Invention**

10           This invention relates to amorphous metal magnetic components; and more particularly, to a generally three-dimensional bulk amorphous metal magnetic component for large electronic devices such as magnetic resonance imaging systems, television and video systems, and electron and ion beam systems.

#### **2.     Description Of The Prior Art**

15           Although amorphous metals offer superior magnetic performance when compared to non-oriented electrical steels, they have long been considered unsuitable for use in bulk magnetic components such as the tiles of poleface magnets for magnetic resonance imaging systems (MRI) due to certain physical properties of amorphous metal and the corresponding fabricating limitations. For example, amorphous metals  
20           are thinner and harder than non-oriented silicon-steel and consequently cause fabrication tools and dies to wear more rapidly. The resulting increase in the tooling and manufacturing costs makes fabricating bulk amorphous metal magnetic

components using such techniques commercially impractical. The thinness of amorphous metals also translates into an increased number of laminations in the assembled components, further increasing the total cost of the amorphous metal magnetic component.

- 5       Amorphous metal is typically supplied in a thin continuous ribbon having a uniform ribbon width. However, amorphous metal is a very hard material making it very difficult to cut or form easily, and once annealed to achieve peak magnetic properties, becomes very brittle. This makes it difficult and expensive to use conventional approaches to construct a bulk amorphous metal magnetic component.
- 10      The brittleness of amorphous metal may also cause concern for the durability of the bulk magnetic component in an application such as an MRI system.

- Another problem with bulk amorphous metal magnetic components is that the magnetic permeability of amorphous metal material is reduced when it is subjected to physical stresses. This reduced permeability may be considerable depending upon the
- 15      intensity of the stresses on the amorphous metal material. As a bulk amorphous metal magnetic component is subjected to stresses, the efficiency at which the core directs or focuses magnetic flux is reduced resulting in higher magnetic losses, increased heat production, and reduced power. This stress sensitivity, due to the magnetostrictive nature of the amorphous metal, may be caused by stresses resulting from magnetic
- 20      forces during operation of the device, mechanical stresses resulting from mechanical clamping or otherwise fixing the bulk amorphous metal magnetic components in place,

or internal stresses caused by the thermal expansion and/or expansion due to magnetic saturation of the amorphous metal material.

### SUMMARY OF THE INVENTION

The present invention provides a low-loss bulk amorphous metal magnetic component having the shape of a polyhedron and being comprised of a plurality of layers of amorphous metal strips. Also provided by the present invention is a method for making a bulk amorphous metal magnetic component. The magnetic component is operable at frequencies ranging from about 50 Hz to 20,000 Hz and exhibits improved performance characteristics when compared to silicon-steel magnetic components operated over the same frequency range. More specifically, a magnetic component constructed in accordance with the present invention and excited at an excitation frequency "f" to a peak induction level " $B_{\max}$ " will have a core loss at room temperature less than "L" wherein L is given by the formula  $L = 0.0074 f (B_{\max})^{1.3} + 0.000282 f^{1.5} (B_{\max})^{2.4}$ , the core loss, the excitation frequency and the peak induction level being measured in watts per kilogram, hertz, and teslas, respectively. Preferably, the magnetic component will have (i) a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 12 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.0 T, or (iii) a core-loss of less than or approximately equal to 70

watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T.

In a first embodiment of the present invention, a bulk amorphous metal magnetic component comprises a plurality of substantially similarly shaped layers of amorphous metal strips laminated together to form a polyhedrally shaped part.

The present invention also provides a method of constructing a bulk amorphous metal magnetic component. In a first embodiment of the method, amorphous metal strip material is cut to form a plurality of cut strips having a predetermined length. The cut strips are stacked to form a bar of stacked amorphous metal strip material and annealed to enhance the magnetic properties of the material and, optionally, to transform the initially glassy structure to a nanocrystalline structure. The annealed, stacked bar is impregnated with an epoxy resin and cured. The preferred amorphous metal material has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

In a second embodiment of the method, amorphous metal strip material is wound about a mandrel to form a generally rectangular core having generally radiused corners. The generally rectangular core is then annealed to enhance the magnetic properties of the material and, optionally, to transform the initially glassy structure to a nanocrystalline structure. The core is then impregnated with epoxy resin and cured. The short sides of the rectangular core are then cut to form two magnetic components having a predetermined three-dimensional geometry that is the approximate size and shape of said short sides of said generally rectangular core. The radiused corners are removed from the long sides of said generally rectangular core and the long sides of

said generally rectangular core are cut to form a plurality of polyhedrally shaped magnetic components having the predetermined three-dimensional geometry. The preferred amorphous metal material has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

5        The present invention is also directed to a bulk amorphous metal component constructed in accordance with the above-described methods.

Bulk amorphous metal magnetic components constructed in accordance with the present invention are especially suited for amorphous metal tiles for poleface magnets in high performance MRI systems; television and video systems; and electron and  
10 ion beam systems. The advantages afforded by the present invention include simplified manufacturing, reduced manufacturing time, reduced stresses (e.g., magnetostrictive) encountered during construction of bulk amorphous metal components, and optimized performance of the finished amorphous metal magnetic component.\

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

15        The invention will be more fully understood and further advantages will become apparent when reference is had to the following detailed description of the preferred embodiments of the invention and the accompanying drawings, wherein like reference numerals denote similar elements throughout the several views, and in which:

Fig. 1A is a perspective view of a bulk amorphous metal magnetic component  
20 having the shape of a generally rectangular polyhedron constructed in accordance with the present invention;

**Fig. 1B** is a perspective view of a bulk amorphous metal magnetic component having the shape of a generally trapezoidal polyhedron constructed in accordance with the present invention;

**Fig. 1C** is a perspective view of a bulk amorphous metal magnetic component  
5 having the shape of a polyhedron with oppositely disposed arcuate surfaces and constructed in accordance with the present invention;

**Fig. 2** is a side view of a coil of amorphous metal strip positioned to be cut and stacked in accordance with the present invention;

**Fig. 3** is a perspective view of a bar of amorphous metal strips showing the cut  
10 lines to produce a plurality of generally trapezoidally-shaped magnetic components in accordance with the present invention;

**Fig. 4** is a side view of a coil of amorphous metal strip which is being wound about a mandrel to form a generally rectangular core in accordance with the present invention; and

15 **Fig. 5** is a perspective view of a generally rectangular amorphous metal core formed in accordance with the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The present invention provides a generally polyhedrally shaped low-loss bulk amorphous metal component. Bulk amorphous metal components are constructed in  
20 accordance with the present invention having various geometries including, but not limited to, rectangular, square, and trapezoidal prisms. In addition, any of the previously mentioned geometric shapes may include at least one arcuate surface, and



preferably two oppositely disposed arcuate surfaces to form a generally curved or arcuate bulk amorphous metal component. Furthermore, complete magnetic devices such as poleface magnets may be constructed as bulk amorphous metal components in accordance with the present invention. Those devices may have either a unitary construction or they may be formed from a plurality of pieces which collectively form the completed device. Alternatively, a device may be a composite structure comprised entirely of amorphous metal parts or a combination of amorphous metal parts with other magnetic materials.

Referring now to the drawings in detail, there is shown in Fig. 1A a bulk amorphous metal magnetic component 10 having a three-dimensional generally rectangular shape. The magnetic component 10 is comprised of a plurality of substantially similarly shaped layers of amorphous metal strip material 20 that are laminated together and annealed. The magnetic component depicted in Fig. 1B has a three-dimensional generally trapezoidal shape and is comprised of a plurality of layers of amorphous metal strip material 20 that are each substantially the same size and shape and that are laminated together and annealed. The magnetic component depicted in Fig. 1C includes two oppositely disposed arcuate surfaces 12. The component 10 is constructed of a plurality of substantially similarly shaped layers of amorphous metal strip material 20 that are laminated together and annealed.

The bulk amorphous metal magnetic component 10 of the present invention is a generally three-dimensional polyhedron, and may be generally rectangular, square or trapezoidal prisms. Alternatively, and as depicted in Fig. 1C, the component 10 may

have at least one arcuate surface 12. In a preferred embodiment, two arcuate surfaces 12 are provided and disposed opposite each other.

A three-dimensional magnetic component 10 constructed in accordance with the present invention and excited at an excitation frequency "f" to a peak induction level "B<sub>max</sub>" will have a core loss at room temperature less than "L" wherein L is given by the formula  $L = 0.0074 f (B_{\max})^{1.3} + 0.000282 f^{1.5} (B_{\max})^{2.4}$ , the core loss, the excitation frequency and the peak induction level being measured in watts per kilogram, hertz, and teslas, respectively. In a preferred embodiment, the magnetic component has (i) a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4 Tesla (T); (ii) a core-loss of less than or approximately equal to 12 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1000 Hz and at a flux density of approximately 1.0 T, or (iii) a core-loss of less than or approximately equal to 70 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T. The reduced core loss of the component of the invention advantageously improves the efficiency of an electrical device comprising it.

The low values of core loss make the bulk magnetic component of the invention especially suited for applications wherein the component is subjected to a high frequency magnetic excitation, e.g., excitation occurring at a frequency of at least about 100 Hz. The inherent high core loss of conventional steels at high frequency

renders them unsuitable for use in devices requiring high frequency excitation. These core loss performance values apply to the various embodiments of the present invention, regardless of the specific geometry of the bulk amorphous metal component.

The present invention also provides a method of constructing a bulk amorphous metal component. As shown in Fig. 2, a roll 30 of amorphous metal strip material is cut into a plurality of strips 20 having the same shape and size using cutting blades 40. The strips 20 are stacked to form a bar 50 of stacked amorphous metal strip material. The bar 50 is annealed, impregnated with an epoxy resin and cured. The bar 50 can be cut along the lines 52 depicted in Fig. 3 to produce a plurality of generally three-dimensional parts having a generally rectangular, square or trapezoidal prism shape. Alternatively, the component 10 may include at least one arcuate surface 12, as shown in Fig. 1C.

In a second embodiment of the method of the present invention, shown in Figs. 4 and 5, a bulk amorphous metal magnetic component 10 is formed by winding a single amorphous metal strip 22 or a group of amorphous metal strips 22 around a generally rectangular mandrel 60 to form a generally rectangular wound core 70. The height of the short sides 74 of the core 70 is preferably approximately equal to the desired length of the finished bulk amorphous metal magnetic component 10. The core 70 is annealed, impregnated with an epoxy resin and cured. Two components 10 may be formed by cutting the short sides 74, leaving the radiused corners 76 connected to the long sides 78a and 78b. Additional magnetic components 10 may be formed by removing the radiused corners 76 from the long sides 78a and 78b, and cutting the long

sides 78a and 78b at a plurality of locations, indicated by the dashed lines 72. In the example illustrated in Fig. 5, the bulk amorphous metal component 10 has a generally three-dimensional rectangular shape, although other three-dimensional shapes are contemplated by the present invention such as, for example, shapes having at least one trapezoidal or square face.

The bulk amorphous metal magnetic component 10 of the present invention can be cut from bars 50 of stacked amorphous metal strip or from cores 70 of wound amorphous metal strip using numerous cutting technologies. The component 10 may be cut from the bar 50 or core 70 using a cutting blade or wheel. Alternately, the component 10 may be cut by electro-discharge machining or with a water jet.

Construction of bulk amorphous metal magnetic components in accordance with the present invention is especially suited for tiles for poleface magnets used in high performance MRI systems, in television and video systems, and in electron and ion beam systems. Magnetic component manufacturing is simplified and manufacturing time is reduced. Stresses otherwise encountered during the construction of bulk amorphous metal components are minimized. Magnetic performance of the finished components is optimized.

The bulk amorphous metal magnetic component 10 of the present invention can be manufactured using numerous amorphous metal alloys. Generally stated, the alloys suitable for use in component 10 are defined by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least one of Si, Al and Ge; with the proviso that (i) up

to ten (10) atom percent of component "M" can be replaced with at least one of the metallic species Ti, V, Cr, Mn, Cu, Zr, Nb, Mo, Ta, Hf, Ag, Au, Pd, Pt, and W, (ii) up to ten (10) atom percent of components (Y + Z) can be replaced by at least one of the non-metallic species In, Sn, Sb and Pb, and (iii) up to about one (1) atom percent of the components (M + Y + Z) can be incidental impurities. As used herein, the term "amorphous metallic alloy" means a metallic alloy that substantially lacks any long range order and is characterized by X-ray diffraction intensity maxima which are qualitatively similar to those observed for liquids or inorganic oxide glasses.

Amorphous metal alloys suitable for the practice of the invention are commercially available, generally in the form of continuous thin strip or ribbon in widths up to 20 cm or more and in thicknesses of approximately 20-25  $\mu\text{m}$ . These alloys are formed with a substantially fully glassy microstructure (e.g., at least about 80% by volume of material having a non-crystalline structure). Preferably the alloys are formed with essentially 100% of the material having a non-crystalline structure. Volume fraction of non-crystalline structure may be determined by methods known in the art such as x-ray, neutron, or electron diffraction, transmission electron microscopy, or differential scanning calorimetry. Highest induction values at low cost are achieved for alloys wherein "M" is iron, "Y" is boron and "Z" is silicon. For this reason, amorphous metal strip composed of an iron-boron-silicon alloy is preferred. More specifically, it is preferred that the alloy contain at least 70 atom percent Fe, at least 5 atom percent B, and at least 5 atom percent Si, with the proviso that the total content of B and Si be at least 15 atom percent. Most preferred is

amorphous metal strip having a composition consisting essentially of about 11 atom percent boron and about 9 atom percent silicon, the balance being iron and incidental impurities. This strip is sold by Honeywell International Inc. under the trade designation METLAS® alloy 2605SA-1.

5       The magnetic properties of the amorphous metal strip appointed for use in component 10 of the present invention may be enhanced by thermal treatment at a temperature and for a time sufficient to provide the requisite enhancement without altering the substantially fully glassy microstructure of the strip. A magnetic field may optionally be applied to the strip during at least a portion, and preferably during at  
10   least the cooling portion, of the heat treatment.

      The magnetic properties of certain amorphous alloys suitable for use in component 10 may be significantly improved by heat treating the alloy to form a nanocrystalline microstructure. This microstructure is characterized by the presence of a high density of grains having average size less than about 100 nm, preferably less  
15   than 50 nm, and more preferably about 10-20 nm. The grains preferably occupy at least 50% of the volume of the iron-base alloy. These preferred materials have low core loss and low magnetostriction. The latter property also renders the material less vulnerable to degradation of magnetic properties by stresses resulting from the fabrication and/or operation of component 10. The heat treatment needed to produce  
20   the nanocrystalline structure in a given alloy must be carried out at a higher temperature or for a longer time than would be needed for a heat treatment designed to preserve therein a substantially fully glassy microstructure. As used herein the terms

amorphous metal and amorphous alloy further include a material initially formed with a substantially fully glassy microstructure and subsequently transformed by heat treatment or other processing to a material having a nanocrystalline microstructure. Amorphous alloys which may be heat treated to form a nanocrystalline microstructure are also often termed, simply, nanocrystalline alloys. The present method allows a nanocrystalline alloy to be formed into the requisite geometrical shape of the finished bulk magnetic component. Such formation is advantageously accomplished while the alloy is still in its as-cast, ductile, substantially non-crystalline form; before it is heat-treated to form the nanocrystalline structure which generally renders it more brittle and more difficult to handle.

Two preferred classes of alloy having magnetic properties significantly enhanced by formation therein of a nanocrystalline microstructure are given by the following formulas in which the subscripts are in atom percent.

A first preferred class of nanocrystalline alloy is  $\text{Fe}_{100-u-x-y-z-w}\text{R}_u\text{T}_x\text{Q}_y\text{B}_z\text{Si}_w$ , wherein R is at least one of Ni and Co, T is at least one of Ti, Zr, Hf, V, Nb, Ta, Mo, and W, Q is at least one of Cu, Ag, Au, Pd, and Pt, u ranges from 0 to about 10, x ranges from about 3 to 12, y ranges from 0 to about 4, z ranges from about 5 to 12, and w ranges from 0 to less than about 8. After this alloy is heat treated to form a nanocrystalline microstructure therein, it has high saturation induction (e.g., at least about 1.5 T), low core loss, and low saturation magnetostriction (e.g. a magnetostriction having an absolute value less than  $4 \times 10^{-6}$ ). Such an alloy is

especially preferred for applications wherein component size must be minimized or for poleface magnet applications requiring a high gap flux.

A second preferred class of nanocrystalline alloy is  $\text{Fe}_{100-u-x-y-z-w}\text{R}_u\text{T}_x\text{Q}_y\text{B}_z\text{Si}_w$ , wherein R is at least one of Ni and Co, T is at least one of Ti, Zr, Hf, V, Nb, Ta, Mo, and W, Q is at least one of Cu, Ag, Au, Pd, and Pt, u ranges from 0 to about 10, x ranges from about 1 to 5, y ranges from 0 to about 3, z ranges from about 5 to 12, and w ranges from about 8 to 18. After this alloy is heat treated to form a nanocrystalline microstructure therein, it has a saturation induction of at least about 1.0T, an especially low core loss, and low saturation magnetostriction (e.g. a magnetostriction having an absolute value less than  $4 \times 10^{-6}$ ). Such an alloy is especially preferred for use in components excited at very high frequency (e.g., an excitation frequency of 1000 Hz or more).

An electromagnet system comprising an electromagnet having one or more poleface magnets is commonly used to produce a time-varying magnetic field in the gap of the electromagnet. The time-varying magnetic field may be a purely AC field, i.e. a field whose time average value is zero. Optionally the time varying field may have a non-zero time average value conventionally denoted as the DC component of the field. In the electromagnet system, the at least one poleface magnet is subjected to the time-varying magnetic field. As a result the pole face magnet is magnetized and demagnetized with each excitation cycle. The time-varying magnetic flux density or induction within the poleface magnet causes the production of heat from core loss therewithin.



Bulk amorphous magnetic components will magnetize and demagnetize more efficiently than components made from other iron-base magnetic metals. When used as a pole magnet, the bulk amorphous metal component will generate less heat than a comparable component made from another iron-base magnetic metal when the two components are magnetized at identical induction and excitation frequency. Furthermore, iron-base amorphous metals preferred for use in the present invention have significantly greater saturation induction than do other low loss soft magnetic materials such as permalloy alloys, whose saturation induction is typically 0.6 - 0.9 T. The bulk amorphous metal component can therefore be designed to operate 1) at a lower operating temperature; 2) at higher induction to achieve reduced size and weight; or, 3) at higher excitation frequency to achieve reduced size and weight, or to achieve superior signal resolution, when compared to magnetic components made from other iron-base magnetic metals.

As is known in the art, core loss is that dissipation of energy which occurs within a ferromagnetic material as the magnetization thereof is changed with time. The core loss of a given magnetic component is generally determined by cyclically exciting the component. A time-varying magnetic field is applied to the component to produce therein a corresponding time variation of the magnetic induction or flux density. For the sake of standardization of measurement the excitation is generally chosen such that the magnetic induction varies sinusoidally with time at a frequency "f" and with a peak amplitude " $B_{max}$ ." The core loss is then determined by known electrical measurement instrumentation and techniques. Loss is conventionally

reported as watts per unit mass or volume of the magnetic material being excited. It is known in the art that loss increases monotonically with  $f$  and  $B_{\max}$ . Most standard protocols for testing the core loss of soft magnetic materials used in components of poleface magnets {e.g. ASTM Standards A912-93 and A927(A927M-94)} call for a sample of such materials which is situated in a substantially closed magnetic circuit, i.e. a configuration in which closed magnetic flux lines are completely contained within the volume of the sample. On the other hand, a magnetic material as employed in a component such as a poleface magnet is situated in a magnetically open circuit, i.e. a configuration in which magnetic flux lines must traverse an air gap. Because of fringing field effects and non-uniformity of the field, a given material tested in an open circuit generally exhibits a higher core loss, i.e. a higher value of watts per unit mass or volume, than it would have in a closed-circuit measurement. The bulk magnetic component of the invention advantageously exhibits low core loss over a wide range of flux densities and frequencies even in an open-circuit configuration.

Without being bound by any theory, it is believed that the total core loss of the low-loss bulk amorphous metal component of the invention is comprised of contributions from hysteresis losses and eddy current losses. Each of these two contributions is a function of the peak magnetic induction  $B_{\max}$  and of the excitation frequency  $f$ . Prior art analyses of core losses in amorphous metals (see, e.g., G. E. Fish, J. Appl. Phys. 57, 3569(1985) and G. E. Fish et al., J. Appl. Phys. 64, 5370(1988)) have generally been restricted to data obtained for material in a closed magnetic circuit.

The total core loss  $L(B_{\max}, f)$  per unit mass of the bulk magnetic component of the invention may be essentially defined by a function having the form

$$L(B_{\max}, f) = c_1 f (B_{\max})^n + c_2 f^q (B_{\max})^m$$

wherein the coefficients  $c_1$  and  $c_2$  and the exponents  $n$ ,  $m$ , and  $q$  must all be determined empirically, there being no known theory that precisely determines their values. Use of this formula allows the total core loss of the bulk magnetic component of the invention to be determined at any required operating induction and excitation frequency. It is generally found that in the particular geometry of a bulk magnetic component the magnetic field therein is not spatially uniform. Techniques such as finite element modeling are known in the art to provide an estimate of the spatial and temporal variation of the peak flux density that closely approximates the flux density distribution measured in an actual bulk magnetic component. Using as input a suitable empirical formula giving the magnetic core loss of a given material under spatially uniform flux density these techniques allow the corresponding actual core loss of a given component in its operating configuration to be predicted with reasonable accuracy.

The measurement of the core loss of the magnetic component of the invention can be carried out using various methods known in the art. A method especially suited for measuring the present component may be described as follows. The method comprises forming a magnetic circuit with the magnetic component of the invention and a flux closure structure means. Optionally the magnetic circuit may comprise a plurality of magnetic components of the invention and a flux closure structure means.

The flux closure structure means preferably comprises soft magnetic material having high permeability and a saturation flux density at least equal to the flux density at which the component is to be tested. Preferably, the soft magnetic material has a saturation flux density at least equal to the saturation flux density of the component.

5 The flux direction along which the component is to be tested generally defines first and second opposite faces of the component. Flux lines enter the component in a direction generally normal to the plane of the first opposite face. The flux lines generally follow the plane of the amorphous metal strips, and emerge from the second opposing face. The flux closure structure means generally comprises a flux closure  
10 magnetic component which is constructed preferably in accordance with the present invention but may also be made with other methods and materials known in the art. The flux closure magnetic component also has first and second opposing faces through which flux lines enter and emerge, generally normal to the respective planes thereof. The flux closure component opposing faces are substantially the same size and shape  
15 to the respective faces of the magnetic component to which the flux closure component is mated during actual testing. The flux closure magnetic component is placed in mating relationship with its first and second faces closely proximate and substantially proximate to the first and second faces of the magnetic component of the invention, respectively. Magnetomotive force is applied by passing current through a first  
20 winding encircling either the magnetic component of the invention or the flux closure magnetic component. The resulting flux density is determined by Faraday's law from the voltage induced in a second winding encircling the magnetic component to be

tested. The applied magnetic field is determined by Ampère's law from the magnetomotive force. The core loss is then computed from the applied magnetic field and the resulting flux density by conventional methods.

Referring to Fig. 5, there is illustrated a component 10 having a core loss which  
5 can be readily determined by the testing method described hereinafter. Long side 78b of core 70 is appointed as magnetic component 10 for core loss testing. The remainder of core 70 serves as the flux closure structure means, which is generally C-shaped and comprises the four generally radiused corners 76, short sides 74 and long side 78a. Each of the cuts 72 which separate the radiused corners 76, the short sides 74, and long  
10 side 78a is optional. Preferably, only the cuts separating long side 78b from the remainder of core 70 are made. Cut surfaces formed by cutting core 70 to remove long side 78b define the opposite faces of the magnetic component and the opposite faces of the flux closure magnetic component. For testing, long side 78b is situated with its faces closely proximate and parallel to the corresponding faces defined by the cuts.  
15 The faces of long side 78b are substantially the same in size and shape as the faces of the flux closure magnetic component. Two copper wire windings (not shown) encircle long side 78b. An alternating current of suitable magnitude is passed through the first winding to provide a magnetomotive force that excites long side 78b at the requisite frequency and peak flux density. Flux lines in long side 78b and the flux closure  
20 magnetic component are generally within the plane of strips 22 and directed circumferentially. Voltage indicative of the time varying flux density within long side

78b is induced in the second winding. Core loss is determined by conventional electronic means from the measured values of voltage and current.

The following examples are provided to more completely describe the present invention. The specific techniques, conditions, materials, proportions and reported data set forth to illustrate the principles and practice of the invention are exemplary and should not be construed as limiting the scope of the invention.

### **Example 1**

#### **Preparation And Electro-Magnetic Testing of an Amorphous Metal Rectangular Prism**

10

$\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 60 mm wide and 0.022 mm thick, was wrapped around a rectangular mandrel or bobbin having dimensions of approximately 25 mm by 90 mm. Approximately 800 wraps of amorphous metal ribbon were wound around the mandrel or bobbin producing a rectangular core form having inner dimensions of approximately 25 mm by 90 mm and a build thickness of approximately 20 mm. The core/bobbin assembly was annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the assembly up to 365° C; 2) holding the temperature at approximately 365° C for approximately 2 hours; and, 3) cooling the assembly to ambient temperature. The rectangular, wound, amorphous metal core was removed from the core/bobbin assembly. The core was vacuum impregnated with an epoxy resin solution. The bobbin was replaced, and the rebuilt, impregnated core/bobbin assembly was cured at 120° C for approximately 4.5 hours. When fully cured, the core was again removed from the core/bobbin assembly. The resulting

20

rectangular, wound, epoxy bonded, amorphous metal core weighed approximately 2100 g.

A rectangular prism 60 mm long by 40 mm wide by 20 mm thick (approximately 800 layers) was cut from the epoxy bonded amorphous metal core with a 1.5 mm thick cutting blade. The cut surfaces of the rectangular prism and the remaining section of the core were etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution. The remaining section of the core was etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution. The rectangular prism and the remaining section of the core were then reassembled into a full, cut core form. Primary and secondary electrical windings were fixed to the remaining section of the core. The cut core form was electrically tested at 60 Hz, 1,000 Hz, 5,000 Hz and 20,000 Hz and compared to catalogue values for other ferromagnetic materials in similar test configurations (National-Arnold Magnetics, 17030 Muskrat Avenue, Adelanto, CA 92301 (1995)). The results are compiled below in Tables 1, 2, 3 and 4.

TABLE 1

Core Loss @ 60 Hz (W/kg)

Flux Density	Material				
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)	Crystalline Fe-3%Si (275 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.3 T	0.10	0.2	0.1	0.1	0.06
0.7 T	0.33	0.9	0.5	0.4	0.3
0.8 T		1.2	0.7	0.6	0.4
1.0 T		1.9	1.0	0.8	0.6
1.1 T	0.59				
1.2 T		2.6	1.5	1.1	0.8
1.3 T	0.75				
1.4 T	0.85	3.3	1.9	1.5	1.1

TABLE 2

Core Loss @ 1,000 Hz (W/kg)

Flux Density	Material				
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)	Crystalline Fe-3%Si (275 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.3 T	1.92	2.4	2.0	3.4	5.0
0.5 T	4.27	6.6	5.5	8.8	12
0.7 T	6.94	13	9.0	18	24
0.9 T	9.92	20	17	28	41
1.0 T	11.51	24	20	31	46
1.1 T	13.46				
1.2 T	15.77	33	28		
1.3 T	17.53				
1.4 T	19.67	44	35		

TABLE 3

Core Loss @ 5,000 Hz (W/kg)

Flux Density	Material			
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.04 T	0.25	0.33	0.33	1.3
0.06 T	0.52	0.83	0.80	2.5
0.08 T	0.88	1.4	1.7	4.4
0.10 T	1.35	2.2	2.1	6.6
0.20 T	5	8.8	8.6	24
0.30 T	10	18.7	18.7	48

TABLE 4

Core Loss @ 20,000 Hz (W/kg)

Flux Density	Material			
	Amorphous Fe <sub>80</sub> B <sub>11</sub> Si <sub>9</sub> (22μm)	Crystalline Fe-3%Si (25 μm)	Crystalline Fe-3%Si (50 μm)	Crystalline Fe-3%Si (175 μm)
		National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron	National-Arnold Magnetics Silectron
0.04 T	1.8	2.4	2.8	16
0.06 T	3.7	5.5	7.0	33
0.08 T	6.1	9.9	12	53
0.10 T	9.2	15	20	88
0.20 T	35	57	82	
0.30 T	70	130		



As shown by the data in Tables 3 and 4, the core loss is particularly low at excitation frequencies of 5000 Hz or more. Thus, the magnetic component of the invention is especially suited for use in poleface magnets.

### Example 2

#### 5                   **Preparation of an Amorphous Metal Trapezoidal Prism**

$\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 48 mm wide and 0.022 mm thick, was cut into lengths of approximately 300 mm. Approximately 3,800 layers of the cut amorphous metal ribbon were stacked to form a bar approximately 48 mm wide and 300 mm long, with a build thickness of approximately 96 mm. The bar was  
10 annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to 365° C; 2) holding the temperature at approximately 365° C for approximately 2 hours; and, 3) cooling the bar to ambient temperature. The bar was vacuum impregnated with an epoxy resin solution and cured at 120° C for approximately 4.5 hours. The resulting stacked, epoxy bonded, amorphous metal bar weighed approximately 9000 g.

15           A trapezoidal prism was cut from the stacked, epoxy bonded amorphous metal bar with a 1.5 mm thick cutting blade. The trapezoid-shaped face of the prism had bases of 52 and 62 mm and height of 48 mm. The trapezoidal prism was 96 mm (3,800 layers) thick. The cut surfaces of the trapezoidal prism and the remaining section of the core were etched in a nitric acid/water solution and cleaned in an ammonium  
20 hydroxide/water solution.

The trapezoidal prism has a core loss of less than 11.5 W/kg when excited at 1000 Hz to a peak induction level of 1.0T.

**Example 3****Preparation of Polygonal, Bulk Amorphous Metal  
Components With Arc-Shaped Cross-Sections**

$\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 50 mm wide and 0.022 mm  
5 thick, was cut into lengths of approximately 300 mm. Approximately 3,800 layers of  
the cut amorphous metal ribbon were stacked to form a bar approximately 50 mm wide  
and 300 mm long, with a build thickness of approximately 96 mm. The bar was  
annealed in a nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to  
365°C; 2) holding the temperature at approximately 365°C for approximately 2 hours;  
10 and, 3) cooling the bar to ambient temperature. The bar was vacuum impregnated with  
an epoxy resin solution and cured at 120°C for approximately 4.5 hours. The resulting  
stacked, epoxy bonded, amorphous metal bar weighed approximately 9200 g.

The stacked, epoxy bonded, amorphous metal bar was cut using electro-  
discharge machining to form a three-dimensional, arc-shaped block. The outer  
15 diameter of the block was approximately 96 mm. The inner diameter of the block was  
approximately 13 mm. The arc length was approximately 90°. The block thickness  
was approximately 96 mm.

$\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon, approximately 20 mm wide and 0.022 mm  
thick, was wrapped around a circular mandrel or bobbin having an outer diameter of  
20 approximately 19 mm. Approximately 1,200 wraps of amorphous metal ribbon were  
wound around the mandrel or bobbin producing a circular core form having an inner  
diameter of approximately 19 mm and an outer diameter of approximately 48 mm. The  
core had a build thickness of approximately 29 mm. The core was annealed in a

nitrogen atmosphere. The anneal consisted of: 1) heating the bar up to 365°C; 2) holding the temperature at approximately 365°C for approximately 2 hours; and, 3) cooling the bar to ambient temperature. The core was vacuum impregnated with an epoxy resin solution and cured at 120°C for approximately 4.5 hours. The resulting  
5 wound, epoxy bonded, amorphous metal core weighed approximately 71 g.

The wound, epoxy bonded, amorphous metal core was cut using a water jet to form a semi-circular, three dimensional shaped object. The semi-circular object had an inner diameter of approximately 19 mm, an outer diameter of approximately 48 mm, and a thickness of approximately 20 mm.

10 The cut surfaces of the polygonal, bulk amorphous metal components with arc-shaped cross sections were etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution.

Each of the polygonal bulk amorphous metal components has a core loss of less than 11.5 W/kg when excited at 1000 Hz to a peak induction level of 1.0T.

15 **Example 4**

**High Frequency Behavior of Low-Loss Bulk Amorphous Metal Components**

The core loss data taken in Example 1 above were analyzed using conventional non-linear regression methods. It was determined that the core loss of a low-loss bulk amorphous metal component comprised of  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$  amorphous metal ribbon could be  
20 essentially defined by a function having the form

$$L(B_{\max}, f) = c_1 f (B_{\max})^n + c_2 f^q (B_{\max})^m.$$

Suitable values of the coefficients  $c_1$  and  $c_2$  and the exponents  $n$ ,  $m$ , and  $q$  were selected to define an upper bound to the magnetic losses of the bulk amorphous metal

component. Table 5 recites the measured losses of the component in Example 1 and the losses predicted by the above formula, each measured in watts per kilogram. The predicted losses as a function of  $f$  (Hz) and  $B_{\max}$  (Tesla) were calculated using the coefficients  $c_1 = 0.0074$  and  $c_2 = 0.000282$  and the exponents  $n = 1.3$ ,  $m = 2.4$ , and  $q =$

5 1.5. The measured loss of the bulk amorphous metal component of Example 1 was less than the corresponding loss predicted by the formula.

TABLE 5

Point	$B_{\max}$ (Tesla)	Frequency (Hz)	Measured Core Loss (W/kg)	Predicted Core Loss (W/kg)
1	0.3	60	0.1	0.10
2	0.7	60	0.33	0.33
3	1.1	60	0.59	0.67
4	1.3	60	0.75	0.87
5	1.4	60	0.85	0.98
6	0.3	1000	1.92	2.04
7	0.5	1000	4.27	4.69
8	0.7	1000	6.94	8.44
9	0.9	1000	9.92	13.38
10	1	1000	11.51	16.32
11	1.1	1000	13.46	19.59
12	1.2	1000	15.77	23.19
13	1.3	1000	17.53	27.15
14	1.4	1000	19.67	31.46
15	0.04	5000	0.25	0.61
16	0.06	5000	0.52	1.07
17	0.08	5000	0.88	1.62
18	0.1	5000	1.35	2.25
19	0.2	5000	5	6.66
20	0.3	5000	10	13.28
21	0.04	20000	1.8	2.61
22	0.06	20000	3.7	4.75
23	0.08	20000	6.1	7.41
24	0.1	20000	9.2	10.59
25	0.2	20000	35	35.02
26	0.3	20000	70	75.29

**Example 5****Preparation of a Nanocrystalline Alloy Rectangular Prism**

$\text{Fe}_{73.5}\text{Cu}_1\text{Nb}_3\text{B}_9\text{Si}_{13.5}$  amorphous metal ribbon, approximately 25 mm wide and 0.018 mm thick, is cut into lengths of approximately 300 mm. Approximately 1,200  
5 layers of the cut amorphous metal ribbon are stacked to form a bar approximately 25 mm wide and 300 mm long, with a build thickness of approximately 25 mm. The bar is annealed in a nitrogen atmosphere. The anneal is carried out by performing the following steps: 1) heating the bar up to 580° C; 2) holding the temperature at approximately 580° C for approximately 1 hour; and, 3) cooling the bar to ambient  
10 temperature. The bar is vacuum impregnated with an epoxy resin solution and cured at 120° C for approximately 4.5 hours. The resulting stacked, epoxy bonded, amorphous metal bar weighs approximately 1200 g.

A rectangular prism is cut from the stacked, epoxy bonded amorphous metal bar with a 1.5 mm thick cutting blade. The face of the prism is approximately 25 mm wide  
15 and 50 mm long. The rectangular prism is 25 mm (1200 layers) thick. The cut surfaces of the rectangular prism are etched in a nitric acid/water solution and cleaned in an ammonium hydroxide/water solution.

The rectangular prism has a core loss of less than 11.5 W/kg when excited at 1000 Hz to a peak induction level of 1.0 T.

20 Having thus described the invention in rather full detail, it will be understood that such detail need not be strictly adhered to but that various changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the present invention as defined by the subjoined claims.

CLAIMS

What is claimed is:

1. A low-loss bulk amorphous metal magnetic component comprising  
5 a plurality of substantially similarly shaped layers of amorphous metal strips  
laminated together to form a polyhedrally shaped part wherein said low-loss  
bulk amorphous metal magnetic component when operated at an excitation  
frequency "f" to a peak induction level  $B_{\max}$  has a core-loss less than "L"  
wherein L is given by the formula  $L = 0.0074 f (B_{\max})^{1.3} + 0.000282 f^{1.5} (B_{\max})^{2.4}$ ,  
10 said core loss, said excitation frequency and said peak induction level being  
measured in watts per kilogram, hertz, and teslas, respectively.

2. A bulk amorphous metal magnetic component as recited by claim  
1, each of said amorphous metal strips having a composition defined essentially  
15 by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at  
least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least  
one of Si, Al and Ge; with the provisos that (i) up to 10 atom percent of  
component "M" can be replaced with at least one of the metallic species Ti, V,  
Cr, Mn, Cu, Zr, Nb, Mo, Ta, Hf, Ag, Au, Pd, Pt, and W, (ii) up to 10 atom  
20 percent of components (Y + Z) can be replaced by at least one of the non-  
metallic species In, Sn, Sb and Pb and (iii) up to about one (1) atom percent of  
the components (M + Y + Z) can be incidental impurities.

3. A bulk amorphous metal magnetic component as recited by claim 2, wherein each of said amorphous metal strips has a composition containing at least 70 atom percent Fe, at least 5 atom percent B, and at least 5 atom percent Si, with the proviso that the total content of B and Si is at least 15 atom percent.

4. A bulk amorphous metal magnetic component as recited by claim 3, wherein each of said amorphous metal strips has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

5. A bulk amorphous metal magnetic component as recited by claim 2, said amorphous metal strips having been heat treated to form a nanocrystalline microstructure therein.

6. A low-loss bulk amorphous metal component as recited by claim 5, wherein each of said amorphous metal strips has a composition defined essentially by the formula  $\text{Fe}_{100-u-x-y-z-w}\text{R}_u\text{T}_x\text{Q}_y\text{B}_z\text{Si}_w$ , wherein R is at least one of Ni and Co, T is at least one of Ti, Zr, Hf, V, Nb, Ta, Mo, and W, Q is at least one of Cu, Ag, Au, Pd, and Pt, u ranges from 0 to about 10, x ranges from about 3 to 12, y ranges from 0 to about 4, z ranges from about 5 to 12, and w ranges from 0 to less than about 8.

7. A low-loss bulk amorphous metal component as recited by claim 5, wherein each of said amorphous metal strips has a composition defined essentially by the formula  $\text{Fe}_{100-u-x-y-z-w}\text{R}_u\text{T}_x\text{Q}_y\text{B}_z\text{Si}_w$ , wherein R is at least one of Ni and Co, T is at least one of Ti, Zr, Hf, V, Nb, Ta, Mo, and W, Q is at least one of Cu, Ag, Au, Pd, and Pt, u ranges from 0 to about 10, x ranges from about 1 to 5, y ranges from 0 to about 3, z ranges from about 5 to 12, and w ranges from about 8 to 18.

8. A bulk amorphous metal magnetic component as recited by claim 1, wherein said component has the shape of a three-dimensional polyhedron with at least one rectangular cross-section.

9. A bulk amorphous metal magnetic component as recited by claim 1, wherein said component has the shape of a three-dimensional polyhedron with at least one trapezoidal cross-section.

10. A bulk amorphous metal magnetic component as recited by claim 1, wherein said component has the shape of a three-dimensional polyhedron with at least one square cross-section.

11. A bulk amorphous metal magnetic component as recited by claim 1, wherein said component includes at least one arcuate surface.



12. A bulk amorphous metal magnetic component as recited by claim 1, wherein said magnetic component has a core-loss of less than or approximately equal to 1 watt-per-kilogram of amorphous metal material when operated at a frequency of approximately 60 Hz and at a flux density of approximately 1.4T.

13. A bulk amorphous metal magnetic component as recited by claim 1, wherein said magnetic component has a core-loss of less than or approximately equal to 12 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 1,000 Hz and at a flux density of approximately 1.0T.

14. A bulk amorphous metal magnetic component as recited by claim 1, wherein said magnetic component has a core-loss of less than or approximately equal to 70 watts-per-kilogram of amorphous metal material when operated at a frequency of approximately 20,000 Hz and at a flux density of approximately 0.30T.

15. A method of constructing a bulk amorphous metal magnetic component comprising the steps of:

(a) cutting amorphous metal strip material to form a plurality of cut strips having a predetermined length;

(b) stacking said cut strips to form a bar of stacked amorphous metal strip material;

5 (c) annealing said stacked bar;

(d) impregnating said stacked bar with an epoxy resin and curing said resin impregnated stacked bar; and

10 (e) cutting said stacked bar at predetermined lengths to provide a plurality of polyhedrally shaped magnetic components having a predetermined three-dimensional geometry.

15 16. A method of constructing a bulk amorphous metal magnetic component as recited by claim 15, wherein said step (a) comprises cutting amorphous metal strip material using a cutting blade, a cutting wheel, a water jet or an electro-discharge machine.

20 17. A bulk amorphous metal magnetic component constructed in accordance with the method of claim 15, wherein said low-loss bulk amorphous metal magnetic component when excited at a frequency  $f$  to a peak induction level  $B_{\max}$  has a core-loss less than  $L$  wherein  $L$  is given by the formula  $L = 0.0074 f (B_{\max})^{1.3} + 0.000282 f^{1.5} (B_{\max})^{2.4}$ , said core loss, said excitation

frequency and said peak induction level being measured in watts per kilogram, hertz, and teslas, respectively.

18. A bulk amorphous metal magnetic component as recited by claim 5 17, wherein each of said cut strips has a composition defined essentially by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least one of Si, Al and Ge; with the provisos that (i) up to 10 atom percent of component "M" can be replaced with at least one of the metallic species Ti, V, Cr, Mn, Cu, Zr, 10 Nb, Mo, Ta, Hf, Ag, Au, Pd, Pt, and W, (ii) up to 10 atom percent of components (Y + Z) can be replaced by at least one of the non-metallic species In, Sn, Sb and Pb; and (iii) up to about one (1) atom percent of the components (M + Y + Z) can be incidental impurities.

15 19. A bulk amorphous metal magnetic component as recited by claim 18, wherein each of said cut strips has a composition containing at least 70 atom percent Fe, at least 5 atom percent B, and at least 5 atom percent Si, with the proviso that the total content of B and Si is at least 15 atom percent.

20 20. A bulk amorphous magnetic component as recited by claim 19 wherein each of said cut strips has a composition defined essentially by the formula  $Fe_{80}B_{11}Si_9$ .

21. A bulk amorphous magnetic component as recited by claim 18 wherein each of said cut strips has been heat treated to form a nanocrystalline microstructure therein.

5

22. A bulk amorphous metal magnetic component as recited by claim 17, wherein said component has the shape of a three-dimensional polyhedron with at least one rectangular cross-section.

10

23. A bulk amorphous metal magnetic component as recited by claim 17, wherein said component has the shape of a three-dimensional polyhedron with at least one trapezoidal cross-section.

15

24. A bulk amorphous metal magnetic component as recited by claim 17, wherein said component has the shape of a three-dimensional polyhedron with at least one square cross-section.

20

25. A bulk amorphous metal magnetic component as recited by claim 17, wherein said component includes at least one arcuate surface.

26. A method of constructing a bulk amorphous metal magnetic component comprising the steps of:

35

(a) winding amorphous metal strip material about a mandrel to form a generally rectangular core having generally radiused corners;

(b) annealing said wound, rectangular core;

(c) impregnating said wound, rectangular core with an epoxy resin and curing said epoxy resin impregnated rectangular core;

(d) cutting the short sides of said generally rectangular core to form two polyhedrally shaped magnetic components having a predetermined three-dimensional geometry that is the approximate size and shape of said short sides of said generally rectangular core;

(e) removing the generally radiused corners from the long sides of said generally rectangular core; and

(f) cutting the long sides of said generally rectangular core to form a plurality of magnetic components having said predetermined three-dimensional geometry.

27. A method of constructing a bulk amorphous metal magnetic component as recited by claim 26, wherein at least one of said steps (d) and (f) comprises cutting amorphous metal strip material using a cutting blade, a cutting wheel, a water jet or an electro-discharge machine.

28. A bulk amorphous metal magnetic component constructed in accordance with the method of claim 26, wherein said low-loss bulk amorphous

36

metal magnetic component when excited at a frequency  $f$  to a peak induction level  $B_{\max}$  has a core-loss less than  $L$  wherein  $L$  is given by the formula  $L = 0.0074 f (B_{\max})^{1.3} + 0.000282 f^{1.5} (B_{\max})^{2.4}$ , said core loss, said excitation frequency and said peak induction level being measured in watts per kilogram, hertz, and teslas, respectively.

29. A bulk amorphous metal magnetic component as recited by claim 28, wherein said amorphous metal strip material has a composition defined essentially by the formula:  $M_{70-85} Y_{5-20} Z_{0-20}$ , subscripts in atom percent, where "M" is at least one of Fe, Ni and Co, "Y" is at least one of B, C and P, and "Z" is at least one of Si, Al and Ge; with the provisos that (i) up to 10 atom percent of component "M" can be replaced with at least one of the metallic species Ti, V, Cr, Mn, Cu, Zr, Nb, Mo, Ta, Hf, Ag, Au, Pd, Pt, and W, (ii) up to 10 atom percent of components (Y + Z) can be replaced by at least one of the non-metallic species In, Sn, Sb and Pb; and (iii) up to about one (1) atom percent of the components (M + Y + Z) can be incidental impurities.

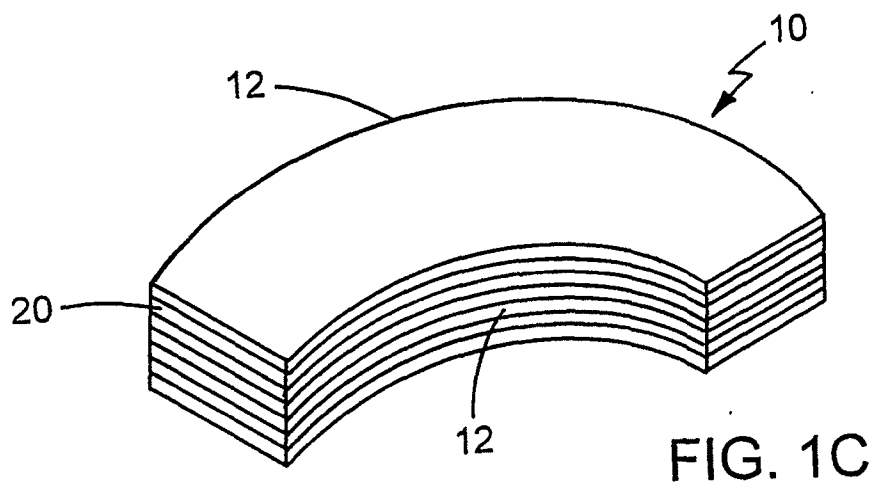
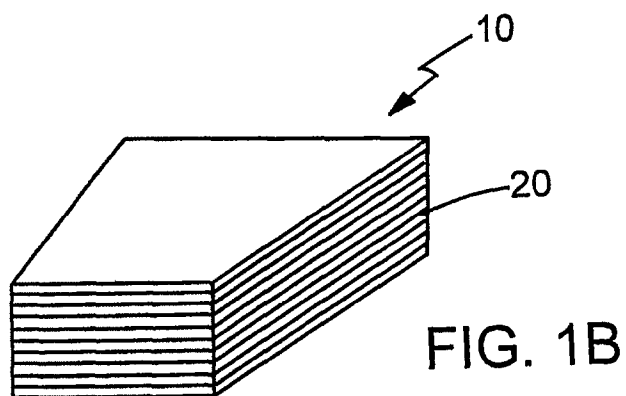
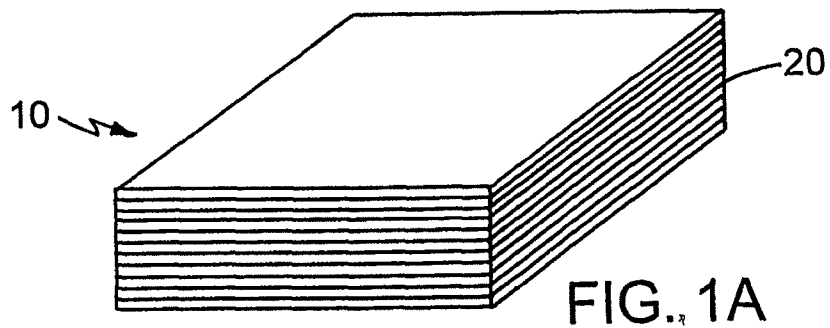
30. A bulk amorphous metal magnetic component as recited by claim 29, wherein said amorphous metal strip material has a composition containing at least 70 atom percent Fe, at least 5 atom percent B, and at least 5 atom percent Si, with the proviso that the total content of B and Si is at least 15 atom percent.

31. A bulk amorphous metal magnetic component as recited by claim 30, wherein said amorphous metal strip material has a composition defined essentially by the formula  $\text{Fe}_{80}\text{B}_{11}\text{Si}_9$ .

5           32. A bulk amorphous magnetic component as recited by claim 29 wherein said amorphous metal strip material has been heat treated to form a nanocrystalline microstructure therein.

10           33. A bulk amorphous metal magnetic component as recited by claim 28, wherein said predetermined three-dimensional geometry is generally rectangular.

          34. A bulk amorphous metal magnetic component as recited by claim 28, wherein said predetermined three-dimensional geometry is generally square.





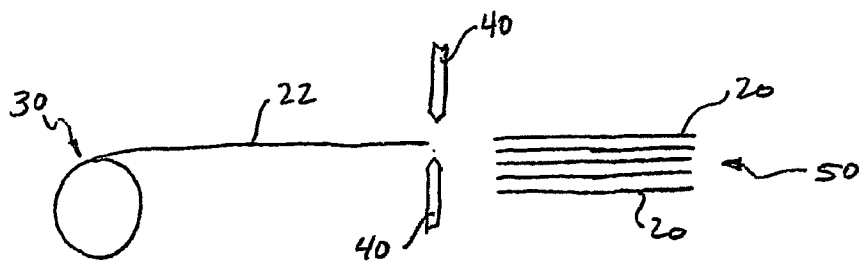


Fig. 2

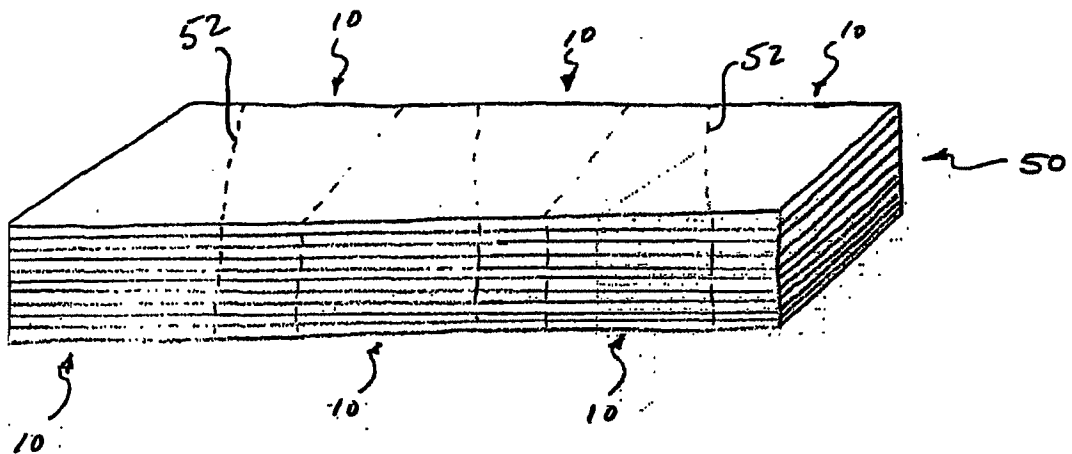
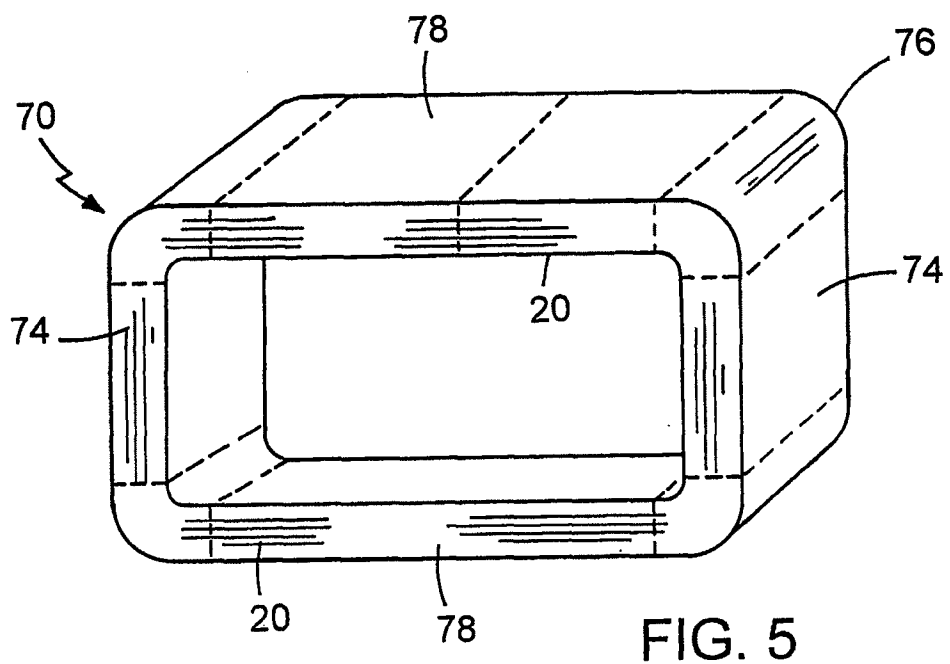
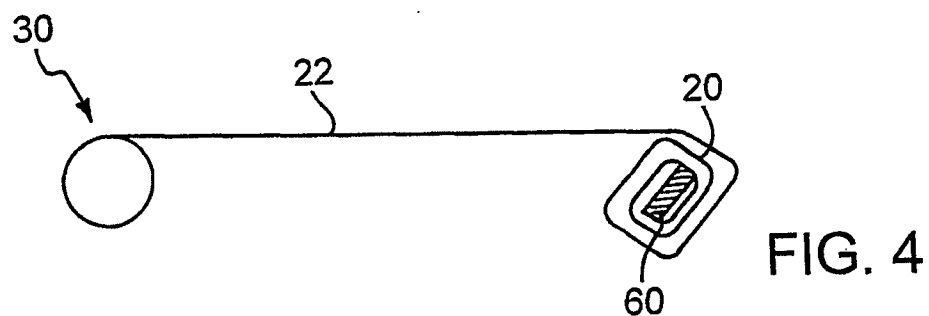


Fig. 3



## INTERNATIONAL SEARCH REPORT

Inter ☐ Application No

PCT/US 01/00099

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 7 H01F3/04 H01F41/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 IPC 7 H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, WPI Data, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 007, no. 267 (E-213), 29 November 1983 (1983-11-29) & JP 58 148419 A (MATSUSHITA DENKO KK), 3 September 1983 (1983-09-03)	1,8
A	abstract	15
X	PATENT ABSTRACTS OF JAPAN vol. 007, no. 267 (E-213), 29 November 1983 (1983-11-29) & JP 58 148418 A (MATSUSHITA DENKO KK), 3 September 1983 (1983-09-03)	1-4,11
A	abstract	26,28-31
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

## ° Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*Z\* document member of the same patent family

Date of the actual completion of the international search

4 April 2001

Date of mailing of the international search report

10/04/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
 Fax: (+31-70) 340-3016

Authorized officer

Decanniere, L

## INTERNATIONAL SEARCH REPORT

Inter Application No

PCT/US 01/00099

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 009, no. 039 (E-297), 19 February 1985 (1985-02-19) & JP 59 181504 A (TOSHIBA KK), 16 October 1984 (1984-10-16) abstract ----	1-4, 26
A	PATENT ABSTRACTS OF JAPAN vol. 010, no. 319 (E-450), 30 October 1986 (1986-10-30) & JP 61 131518 A (TOSHIBA CORP), 19 June 1986 (1986-06-19) abstract ----	1, 15, 16
A	WO 94 14994 A (ALLIED SIGNAL INC) 7 July 1994 (1994-07-07) page 17, line 21 - line 30; claims 1, 21, 24 ----	1-3, 5, 9, 32
A	G.E.FISH: "High permeability iron-based metallic glasses for line frequency applications" JOURNAL OF APPLIED PHYSICS., vol. 57, no. 1, 15 April 1985 (1985-04-15), pages 3569-3571, XP000990110 AMERICAN INSTITUTE OF PHYSICS. NEW YORK., US ISSN: 0021-8979 cited in the application page 3569, column 1 -column 2 ----	1, 2, 5, 6, 26, 29, 32
P, X	WO 00 28556 A (ALLIED SIGNAL INC) 18 May 2000 (2000-05-18) cited in the application claims 1-34; figures 1-5 -----	1-34

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 58148419 A	03-09-1983	NONE	
JP 58148418 A	03-09-1983	NONE	
JP 59181504 A	16-10-1984	JP 1870433 C JP 5044165 B	06-09-1994 05-07-1993
JP 61131518 A	19-06-1986	JP 1904057 C JP 6030309 B	08-02-1995 20-04-1994
WO 9414994 A	07-07-1994	AT 195768 T CA 2151833 A CN 1094097 A,B DE 69329297 D DE 69329297 T EP 0675970 A ES 2150484 T JP 8505188 T US 5593518 A US 5593513 A US 5871593 A	15-09-2000 07-07-1994 26-10-1994 28-09-2000 22-02-2001 11-10-1995 01-12-2000 04-06-1996 14-01-1997 14-01-1997 16-02-1999
WO 0028556, 56 A		NONE	